Wind Turbine

A wind turbine works by using the force of the wind to spin blades that are connected to a generator, which converts the mechanical energy of the spinning blades into electrical energy. Wind creates a pressure difference on the blades, similar to an airplane wing, generating "lift" that causes the rotor to spin. This rotation is transferred to a gearbox (if present), which increases the speed, before spinning a generator that produces electricity.

1. Wind turns the rotor blades

Aerodynamic force:

The propeller-like blades are shaped like airfoils, which create a low-pressure area on one side and a higher-pressure area on the other as wind flows

over them.
Lift:
This difference in air pressure results in a force called "lift," which is stronger than the "drag" from the wind pushing against the front of the blade.
Rotation:
The force of the lift makes the blades and the attached rotor spin, similar to how a propeller works.

2. The rotor spins a generator
Mechanical connection: The spinning rotor is connected to a drive shaft that turns the generator.
Gearbox (optional): In some turbines, a gearbox increases the rotational speed of the shaft to a level suitable for the generator to produce electricity efficiently.
Direct-drive systems: Other turbines, known as direct-drive turbines, have the rotor directly connected to the generator without a gearbox.
3. The generator produces electricity
Electromagnetic principles: The rotating generator converts the mechanical energy from the spinning shaft into electrical energy, using principles of electromagnetism to generate an electric current.

- Key Components and Safety Features

Nacelle:

This housing at the top of the tower contains the gearbox, rotor, and generator.

Controller:

Monitors wind speed via an anemometer and can control the rotor's speed to prevent damage in high winds.

Brake:

A safety mechanism housed in the nacelle to stop the rotor in emergencies.

Yaw Drive:

Allows the turbine to rotate on its tower to face into the wind for maximum energy capture.

A typical onshore wind turbine produces enough annual energy (over 6 million kWh) to power approximately 1,500 average households, with its output varying based on factors like wind speed, turbine size, and location. While turbines operate at their nameplate capacity (e.g., 2.5-3 MW for onshore) at their rated wind speed, they also have a cut-in speed for starting generation and a cut-out speed to prevent damage from extreme winds.

- Factors Affecting Output

Wind Speed:

Power output is highly dependent on wind speed; a doubling of wind speed can increase power by a factor of eight because power is related to the cube of the velocity.

Turbine Size:

Larger turbines generally have higher capacity and can produce more electricity. For example, large commercial turbines can range from 2 MW to over 15 MW, while smaller residential units might be 2-10 kW.

Turbine Efficiency:

The design and efficiency of the turbine play a role in how much energy is captured and converted to electricity.

Location:

Offshore wind turbines can often power more homes than onshore turbines because they are typically larger and benefit from stronger, more consistent winds.

- Operational Range

Cut-in Speed: Wind turbines begin generating electricity when wind speed reaches a minimum

threshold, usually around 4 m/s (meters per second).
Rated Wind Speed: As wind speed increases, output rises until it hits the turbine's rated wind speed (around 12-13 m/s), at which point it delivers its maximum, or "nameplate," capacity.
Cut-out Speed: In very high wind speeds, turbines are shut down to prevent damage.

- Annual Energy Production
An average onshore wind turbine (2.5–3 MW) can generate over 6 million kilowatt-hours (kWh) per year.
This is enough electricity to power around 1,500 average households for a year.

- Wind Energy and Power Calculations
https://www.e-education.psu.edu/emsc297/node/649

see also
- Nuclear Reactors & Small Modular Reactors
https://archive.org/details/nuclear-reactors-small-modular-reactors

- How Generators produce electrical power
https://archive.org/details/ac-generators-parallel-operation-250707-205447

- Power inverter

https://archive.org/details/power-inverter/

- 60-50-hz Frequency applications

https://archive.org/details/60-50-hz-frequency-applications-250705-234638

- Power Supply

https://archive.org/details/power-supply-wikipedia

Resources:

https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php

https://www.repsol.com/en/energy-move-forward/energy/wind-turbine/index.cshtml

https://www.energy.gov/eere/wind/how-do-wind-turbines-work

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https://loeriesfonteinwind.co.za/wind-energy-library/wind-turbine-facts/

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https://www.bgbinnovation.com/knowledge/news-and-articles/how-much-energy-does-a-wind-turbine-produce

https://www.climatecouncil.org.au/resources/offshore-wind-fact-sheet/

https://www.ewea.org/wind-energy-basics/faq/